APPLICATION FOR UNITED STATES LETTERS PATENT

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INVENTION: INK JET PRINTING APPARATUS AND INK
                JET PRINTING METHOD

S P E C I F I C A T I O N

This application claims priority from Japanese Patent Application Nos. 2002-215845 filed July 24, 2002 and 2002-215846 filed July 24, 2002, which are incorporated hereinto by reference.

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BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

10   The present invention relates to an ink jet printing apparatus and an ink jet printing method which form an image by ejecting ink droplets from an ink jet print head having an array of nozzles. More specifically, the present invention relates to an ink

15   jet printing apparatus and an ink jet printing method which analyze and correct causes of printed image quality degradations and thereby form a high-quality printed image.

It is noted that this invention is applicable to

20 all apparatus that use print media such as paper, cloth, leather, nonwoven cloth, OHP sheets and even metal sheets. Examples of applicable device include office equipment, such as printers, copying machines and facsimiles, and industrial manufacturing devices.

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BRIEF DESCRIPTION OF THE RELATED ART

As information processing devices, such as copying machines, word processors and computers, and communication devices become more widespread, ink jet printing apparatus are rapidly proliferating as one of

5 printing apparatus for outputting digital images processed by these devices. For faster printing speed, these printing apparatus use a print head having a large number of integrally formed nozzles each made up of an ink ejection opening and a liquid path. Further,

10 with a growing trend toward information processing devices going color in recent years, there is an increasing demand on the printing apparatus for a color printing capability. To meet this demand, common ink jet printing apparatus employ a plurality of

15 parallelly arranged print heads for ejecting ink droplets of different colors.

The ink jet printing apparatus ejects droplets of ink, a recording liquid, onto a print medium such as paper to form dots thereon. Since the ink jet printing

20 apparatus keeps the print head out of contact with the print medium, a printing operation can be performed with low noise. Further, since the density of ink ejection nozzles can be increased, it is possible to enhance the resolution of an image and increase the

25 speed of the printing operation inexpensively. Another advantage of the ink jet printing apparatus is that it does not require special processing such as

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development and fixing and can produce high-quality images on such print media as plain paper at low cost.

Because of these advantages, the ink jet printing apparatus have found a wide range of applications.

5 Particularly, an on-demand type ink jet printing apparatus will attract an ever-increasing demand in the future since it can easily incorporate a color printing technology and can also be reduced in size and simplified. Further, as more and more printing

10 apparatus adopt the color printing, there is an increasing trend for higher image quality and faster printing speed.

The conventional printing apparatus described above, however, have the following problems. In the

15 conventional ink jet printing apparatus using ink jet print heads each having a plurality of arrayed nozzles, when one or more nozzles are clogged or fail to be driven normally for some reason, dots to be printed by these nozzles fail to be printed on a print medium. As

20 such, unprinted portions appear in the form of bands (white bands or stripes) on an image, resulting in causing noticeable degradation of an image quality depending on the grade of appearance of stripe-like unprinted portions. Further, when one or more nozzles

25 fall into an ejection state significantly different from that of other normal nozzles and if a printing operation is continued in this state, white bands or

stripes due to uneven densities sometimes appear on the image, greatly impairing an image quality.

In the event that some nozzles fail to eject ink in an appropriate ejection state, it has been proposed to perform the following methods to alleviate image quality degradations caused by failed or faulty nozzles. The conventional methods that give priorities to an image quality include an ink ejection performance recovery method using a cleaning mechanism and a so-called multipass printing method that prints the same area of a print medium multiple times using a plurality of complementary nozzle groups to complete an image. The multipass printing method, however, has a problem that it takes a lot of time because a plurality of printing operations are performed on every single print area. The ejection performance recovery method using, for example, a cleaning technique also requires much time and consumes an additional volume of ink that does not contribute directly to printing. Because the ejection performance recovery method increases a running cost and is not desirable from an ecological point of view, it is desired that the number of times that the recovery operation is executed be limited to a minimum.

A technique using a so-called head shading to prevent a density variations of a printed image and thereby improve a printed image quality has also been

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developed. A commonly know head shading technique involves printing a test pattern of a uniform grayscale value on a print medium, optically detecting density variations, and performing corrections, such

5   as addition or subtraction, on the grayscale values of an output image as it is printed.

Further, in an ink jet printer having print heads each with a plurality of arrayed ink ejection nozzles, a test pattern of uniform grayscale value is output

10 and print density deviations (or print density variations) are optically measured. It is assumed that the print density variations are caused by variations in ejection volume among nozzles. Efforts have been made to improve the density or ejection volume

15 variations among nozzles as by correcting an ink ejection drive method according to the density variations or by performing a gamma correction of the grayscale on that part of an image corresponding each nozzle.

20 Such a technique to correct a density variation of a printed image is disclosed, for example, in Japanese Patent Application Publication No. 3-33508(1991), Japanese Patent Application Laid-open Nos. 61-283273(1986), 3-166959(1991), and 7-242004(1995). The

25 above image quality improvement effort using the head shading, however, is basically intended to correct variations in volume of ink droplet ejected from each

nozzle. For example, the head shading is not intended
to improve the image quality to an optimum level when
an ink droplet ejected from a faulty nozzle landed on
a position significantly far from an ideal position
5   i.e. failed to land on an ideal position. Particularly
in a full-multiple type ink jet printing apparatus
using full-line heads of a so-called full-line
printing system, which completes an image associated
with a particular print head by performing only one
10 scan of the print head relative to a print medium,
there is a call for further image quality improvements.

    To meet this requirement, the inventor of this
invention also proposed the following ink jet printing
apparatus. In this printing apparatus, measurements
15 are made, for each print head, of deviations between
actual positions on a print medium at which ink
droplets ejected from individual nozzles landed and
ideal landing positions on the print medium at which
the ink droplets are intended to land (pixel formation
20 positions on a print matrix). Then, nozzles that have
caused ink droplets to deviate from the intended print
matrix are identified. Image data and nearby image
data corresponding to the identified nozzles is
corrected to eliminate the landing position deviations.
25   This method is very useful because, if there is a
variety of factors from ink ejection to flying to
landing that cause ink droplet landing position

deviations, a satisfactory image can be formed at all times regardless of the presence of such factors.

Furthermore, with so-called elongate print heads with nozzles arrayed over a distance in excess of one inch, a problem arises that a volume of image data to be processed becomes large when the nozzles are arranged at a high density of 300 dpi or more. For example, in a print head having nozzles arrayed at 600 dpi over an A4-size distance (about 8 inches), a total number of nozzles reaches as many as 4,800. Performing the above-mentioned deviation correction processing on all of these nozzles requires a huge volume of data to be processed. This takes a lot of time during printing, slowing down an operation speed of the apparatus as a whole. To eliminate this problem requires a costly processor capable of high-speed processing.

Further, if some trouble occurs with a part of the nozzle column, conventionally, due to the presence of such defective nozzle, the print head is obliged to be treated as a low quality print head, which may resulting in a disposal of the print head. In the case of elongate print heads, this practice wastes a large number of normally functioning nozzles, posing a serious problem in terms of cost and ecology.

Furthermore, such elongate nozzles as described above have a greater chance of experiencing nozzle ejection characteristic variations. For example,

nozzles with ink ejection volume variations or those
with landing position deviations may concentrate in a
part of the whole nozzles. In the conventional
practice print heads with some trouble are all
5   disposed of as faulty products. However, among the
print heads treated as faulty products, there are not
a few products whose ejection volume variations and _
landing position deviations are small and which have
only a few faulty nozzles. Making use of these
10 _ discarded products will reduce a manufacturing cost of
the apparatus and its realization is being called for.

SUMMARY OF THE INVENTION

15   The present invention has been accomplished with a
view to overcoming the aforementioned drawbacks and
provides an ink jet printing apparatus and an ink jet
printing method which, if a print head has a faulty
nozzle that projects ink droplets with a large
20 deviation from an intended position, can prevent
unwanted visible bands or stripes from showing in a
printed image, thus assuring a high-quality image with
an appropriate grayscale representation.
       To achieve the above objective, the present
25 invention has the following configuration.
       In one aspect, the present invention provides an
ink jet printing apparatus which forms an image on a

print medium by moving a print head having an array of
nozzles and the print medium relative to each other
and at the same time ejecting ink droplets from the
nozzles according to print data of the image to be

5   printed, the ink jet printing apparatus comprising: a
nozzle information generation means for generating
nozzle information representing an ejection
characteristic of each nozzle according to a landing
state on the print medium of the ink droplet ejected

10   from each nozzle; an estimation means for estimating,
based on the nozzle information generated by the
nozzle information generation means and the print data,
an effect that the ink droplet ejected from each
nozzle has on the image to be formed; a correction

15   information generation means for generating correction
information to correct an ink ejection condition of
each nozzle according to a result of estimation by the
estimation means; and a control means for controlling
a driving of the nozzles according to the print data

20   and the correction information.

In another aspect, the present invention provides
an ink jet printing method which forms an image on a
print medium by moving a print head having an array of
nozzles and the print medium relative to each other

25   and at the same time ejecting ink droplets from the
nozzles according to print data of the image to be
printed, the ink jet printing method comprising: a

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nozzle information generation step for generating
nozzle information representing an ejection
characteristic of each nozzle according to a landing
state on the print medium of the ink droplet ejected
5   from each nozzle; an estimation step for estimating,
based on the nozzle information generated by the
nozzle information generation step and the print data,
an effect that the ink droplet ejected from each
nozzle has on the image to be formed; a correction
10   information generation step for generating correction
information to correct an ink ejection condition of
each nozzle according to a result of estimation by the
estimation step; and a control step for controlling a
driving of the nozzles according to the print data and
15   the correction information.

In still another aspect, the present invention
provides an ink jet printing apparatus which forms an
image on a print medium by moving a print head having
an array of nozzles and the print medium relative to
20   each other and at the same time ejecting ink droplets
from the nozzles according to print data of the image
to be printed, the ink jet printing apparatus
comprising: a deviation correction means for
performing an ink dot deviation correction based on
25   deviation data representing an amount of deviation, or
a difference, between an actual landing position of an
ink dot formed on the print medium by the ink droplet

ejected from each nozzle and an ideal landing position
of the ink dot; and a control means for selectively
causing the deviation correction means to execute the
dot deviation correction according to the amount of
5   deviation.

In a further aspect, the present invention provides
an ink jet printing apparatus which forms an image on
a print medium by moving a print head having an array
of nozzles and the print medium relative to each other
10   and at the same time ejecting ink droplets from the
nozzles according to print data of the image to be
printed, the ink jet printing apparatus comprising: a
grayscale correction means for performing an ink dot
grayscale correction according to density difference
15   data representing a density difference between an
actual density of an ink dot formed on the print
medium and an ideal density of the dot; a deviation
correction means for performing an ink dot deviation
correction based on deviation data representing an
20   amount of deviation, or a difference, between an
actual landing position of an ink dot formed on the
print medium by the ink droplet ejected from each
nozzle and an ideal landing position of the ink dot;
and a control means for controlling the grayscale
25   correction means and the deviation correction means
according to at least the density difference and the
amount of deviation.

In a further aspect, the present invention provides an ink jet printing method which forms an image on a print medium by moving a print head having an array of nozzles and the print medium relative to each other

5   and at the same time ejecting ink droplets from the nozzles according to print data of the image to be printed, the ink jet printing method comprising: a deviation correction step for performing an ink dot deviation correction based on deviation data

10   representing an amount of deviation, or a difference, between an actual landing position of an ink dot formed on the print medium by the ink droplet ejected from each nozzle and an ideal landing position of the ink dot; and a control step for selectively causing

15   the deviation correction step to execute the dot deviation correction according to the amount of deviation.

In a further aspect, the present invention provides an ink jet printing method which forms an image on a

20   print medium by moving a print head having an array of nozzles and the print medium relative to each other and at the same time ejecting ink droplets from the nozzles according to print data of the image to be printed, the ink jet printing method comprising: a

25   grayscale correction step for performing an ink dot grayscale correction according to density difference data representing a density difference between an

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actual density of an ink dot formed on the print
medium and an ideal density of the dot; a deviation
correction step for performing an ink dot deviation
correction based on deviation data representing an
5   amount of deviation, or a difference, between an
actual landing position of an ink dot formed on the
print medium by the ink droplet ejected from each
nozzle and an ideal landing position of the ink dot;
and a control step for controlling the grayscale
10   correction means and the deviation correction means
according to at least the density difference and the
amount of deviation.

In this specification, the word "nozzles" means a
construction that includes not only the openings
15   through which to eject ink but also cylindrical liquid
paths or spaces communicating with the openings and
accommodating the ink and ejection energy generation
means (e.g., electrothermal transducers, piezoelectric
elements, etc.) for generating an energy to eject the
20   ink in the liquid paths from the ejection openings.

With the invention having the above-described
construction, since the dot deviation correction is
performed based on the deviation data representing an
amount of deviation, or a difference, between an
25   actual landing position of an ink dot formed on the
print medium by an ink droplet ejected from each
nozzle of the print head and an ideal landing position

of the ink dot and since the deviation correction
means is made to selectively execute the dot deviation
correction according to the amount of deviation, even
if the print head has a faulty nozzle whose dot

5 landing position greatly deviates from an intended
position, it is possible to produce a high-quality
image with no visible bands or stripes. Therefore,
print heads with such faulty nozzles do not have to be
replaced and can be used for a long period of time.

10 Not only does this reduces the running cost of the
apparatus significantly but it is also desirable from
an ecological point of view. This invention therefore
can practically improve a yield of print heads in a
production line and reduce a production cost of the

15 print heads.

Further, since the dot deviation correction by the
deviation correction means can be executed only when
the correction is found necessary based on the amount
of deviation, the processing time required by the

20 correction operation can be minimized, assuring an
efficient printing operation.

The advantages of this invention described above
are particularly notable with a printing system in
which an image is completed with a single printing

25 scan of a print head having an array of nozzles. This
invention can also be applied to a so-called multipass
printing in which one and the same print area is

scanned multiple times by different nozzle groups.
Undesired stripes or bands in a printed image that are
already reduced by the multipass printing can further
be reduced by this invention. This invention therefore
5 is applicable to any type of ink jet printing system.

The above and other objects, effects, features and
advantages of the present invention will become more
apparent from the following description of embodiments
thereof taken in conjunction with the accompanying
10 drawings.

The above and other objects, effects, features and
advantages of the present invention will become more
apparent from the following description of embodiments
thereof taken in conjunction with the accompanying
15 drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a front view showing an outline
20 configuration of an ink jet printing apparatus
according to one embodiment of the present invention;

Fig. 2 is an enlarged schematic view showing a
construction of an ink jet print head A of Fig. 1;

Fig. 3 is a block diagram showing an example
25 configuration of a control system in the embodiment of
this invention;

Fig. 4A is an example step chart for identifying

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faulty nozzles in a print head, formed by a print head having normal nozzles;

Fig. 4B is an example step chart for identifying faulty nozzles in a print head, formed by a print head having faulty nozzles at 18th, 28th and 30th position;

Fig. 5A is an example dot chart for identifying faulty nozzles in a print head, formed by a print head having normal nozzles;

Fig. 5B is an example dot chart for identifying faulty nozzles in a print head, formed by a print head having faulty nozzles at 18th, 28th and 30th position;

Fig. 6 illustrates a variety of shapes of ink dots formed on a print medium by ink droplets ejected from nozzles of a print head;

Fig. 7A is a schematic diagram showing an ideal matrix applied to the embodiment of this invention and ink droplets that have landed on the ideal matrix on a print medium in an ideal manner;

Fig. 7B is a schematic diagram showing an ideal matrix applied to the embodiment of this invention and ink droplets that have landed on the ideal matrix on a print medium not in an ideal manner;

Fig. 8 is a flow chart showing an example control operation in a first embodiment of the invention;

Fig. 9A is an explanatory diagram showing how a plurality of ink dots formed by ink droplets ejected from nozzles affect one of ideal matrix lines in the

first embodiment, and also illustrating a print head, an ideal matrix, ink droplets that landed in an ideal manner, and ink droplets that failed to land in an ideal manner;

5   Fig. 9B is an explanatory diagram showing how a plurality of ink dots formed by ink droplets ejected from nozzles affect one of ideal matrix lines in the first embodiment, and also illustrating in a magnified state three rows of dots d(m-1), d(m), d(m+1) at a

10   center of the dot group of Fig. 9A;

Fig. 10 is an explanatory diagram showing how ink dots formed by ink droplets ejected from nozzles affect one unit matrix in the first embodiment, and also illustrating in a magnified state three rows of

15   dots d(m-1), d(m), d(m+1) at a center of the dot group of Fig. 9A;

Fig. 11A is an explanatory diagram showing a plurality of ink dots ejected from nozzles that are deviated from their intended positions in the first

20   embodiment;

Fig. 11B is an explanatory diagram showing a method of calculating a degree to which a plurality of ink dots affect one of ideal matrix lines;

Fig. 12 is a flow chart showing a control operation

25   in a second embodiment of the invention;

Fig. 13 is a flow chart showing a control operation in a third embodiment of the invention;

Fig. 14 is a flow chart showing a control operation in a fourth embodiment of the invention;

Fig. 15A is an example step chart for identifying faulty nozzles in a print head, formed by a print head having normal nozzles;

Fig. 15B is an example step chart for identifying faulty nozzles in a print head, formed by a print head having faulty nozzles at 18th, 28th and 30th position; and

Fig. 16 is a flow chart showing an example control operation in one embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Now, embodiments of the present invention will be described in detail by referring to the accompanying drawings.

Fig. 1 is a plan view showing an outline construction of an ink jet printing apparatus used in embodiments of the present invention. Mounted on a carriage 20 are a plurality of ink jet print heads 21 (21-1 to 21-4), each of which has an array of nozzles or ink ejection ports. Designated 21-1, 21-2, 21-3 and 21-4 are ink jet print heads (referred to simply as print heads) for ejecting a black (K), cyan (C), magenta (M) and yellow (Y) ink, respectively. In an inside (or liquid path) of each of the ink nozzles of

each print head 21 is provided a heating element
(electrothermal transducer) that generates a thermal
energy for ejecting ink. Ink cartridges 22 each
comprise an ink jet print head 21-1 to 21-4 and an ink
5 tank 22-1 to 22-4.

Control and other signals to the ink jet print
heads 21 are sent through a flexible cable 23. A print
medium 24, such as OHP sheet, glossy paper, glossy
film and postcard, is supplied through transport
10 rollers not shown to pairs of opposing discharge
rollers 25 that hold the print medium and are driven
by a feed motor 26 to feed it in a direction of arrow
(subscan direction). The carriage 20 is movably
supported on a guide shaft 27 and a linear encoder 28.
15 The carriage 20 is driven by a carriage motor 30
through a drive belt 29 to reciprocate along the guide
shaft 27 in a main scan direction crossing (in this
case, perpendicular to) the subscan direction. When
the carriage 20 is reciprocally moved, a pulse signal
20 output from the linear encoder 28 is counted to
determine the current position of the carriage 20. As
the carriage 20 is driven, the heating elements in the
print heads 21 are energized according to the print
signal to eject ink droplets onto a print medium to
25 form an image.

At a home position of the carriage 20 which is set
outside a printing operation region over the print

medium in the main scan direction, a recovery unit 32 with a cap portion 31 is installed. When the printing operation is not performed, the carriage 20 is moved to the home position where ink ejection faces of the print heads 21 are hermetically capped with associated caps 31-1 to 31-4 of the cap portion 31 to prevent a possible clogging of the nozzles caused by increased viscosity of ink or solidified ink from ink solvent evaporation or by adhesion of foreign matter such as dust.

The capping function of the cap portion 31 is also used for an idle ejection, which causes the nozzles to eject ink into the cap portion 31, that is out of contact with the nozzles, to prevent a faulty ejection and clogging of those nozzles having low printing operation frequencies. The capping function is also used to recover the ejection performance of faulty nozzles by activating a pump not shown to draw ink from the nozzles, with the ink ejection faces hermetically capped with the cap portion 31. Denoted 33 is an ink receiving portion. When each print head 21-1 to 21-4 passes over the ink receiving portion 33 immediately before starting a printing operation, the print head performs a preliminary ejection toward the ink receiving portion 33. Further, a wipe member (such as a blade) not shown is installed by the side of the cap portion 31 to clean the ink ejection faces of the

print heads 21.

Next, Fig. 2 is an enlarged schematic diagram showing a construction of the print heads 21 described above. In Fig. 2, the print heads each have a large number of ink ejection nozzles n arrayed in a direction almost perpendicular to the main scan direction. While in this figure the nozzles in each print head are arranged in two columns, they may be arranged in one column or in three or more columns. They do not have to be arranged in a straight line. Further, as shown in Fig. 2, an interval W1 between adjacent nozzles in the subscan direction is called a resolution of a print head or a nozzle pitch or a nozzle density.

The print heads can print on an area corresponding to a width W of the nozzle column by ejecting ink as they are moved in the direction of arrow (main scan direction). The printing operation (ink ejection operation) can be done in a forward or backward direction or in both directions. Further, the print heads are prepared in the same number as that of the ink colors used for printing. For example, when three colors, cyan, magenta and yellow, are used for full-color printing, three print heads are prepared. When a monochromatic printing is performed using only a black ink, one print head need only to be prepared. In a printing using dark and light inks, as many print

heads as color inks, such as dark cyan, light cyan, dark magenta, light magenta, dark black, light black, dark yellow and light yellow, need to be prepared. It is also possible to use a print head for ejecting a
5   special color ink.

The ink jet printing system applicable to this invention is not limited to the bubble jet (tradename) system using heating elements (heaters). For example, in a continuous type which continuously ejects ink
10   droplets for atomization, a charge control system and a dispersion control system may be used. Further, in an on-demand type which ejects ink droplets as required, a pressure control system that ejects ink droplets from orifices by mechanical vibrations of
15   piezoelectric elements may be employed.

Fig. 3 is a block diagram showing an example configuration of a control system of an ink jet printing apparatus used in embodiments of the present invention.
20   In Fig. 3, reference number 1 represents an image data input unit for inputting multivalued image data from an image input device, such as scanner and digital camera, and multivalued image data stored, for example, in a hard disk of a personal computer; 2
25   represents an operation unit having various keys for setting a variety of parameters and for starting a printing operation; and 3 represents a CPU as a

control means for controlling various calculation operations and control actions described later that are executed according to programs in a storage medium.

Designated 4 is a storage media which stores a
5 control program group 4b including a control program for controlling the printing apparatus and an error processing program, and nozzle profile information 4a. The printing operations in this embodiment are executed by these programs. The storage media 4
10 storing these programs may use a ROM, FD, CD-ROM, HD, memory card, and magnetooptical disk. Denoted 5 is a RAM that is used as a work area for the programs in the storage media 4, a temporary save area for error processing, and a work area for image processing. The
15 RAM 5 can also be used in the following manner. After a variety of tables are copied from the storage media 4 into the RAM 5, the content of the tables may be changed and the image processing may be performed by referring to the modified tables.

20 Denoted 6 is an image data processing unit which quantizes the input multivalued image data into N-value image data for each pixel and generates ejection pattern data based on quantized grayscale value "T" at each pixel. For example, when multivalued image data
25 represented by 8 bits (256 grayscale levels) is entered into the image data input unit 1, the image data processing unit 6 needs to convert the grayscale

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value of the image data into 25(=24+1)-value data.
While the processing to transform the input grayscale
image data into T-value data uses a multivalued error-
spreading method, the T-value data generation

5   processing may employ any desired half-tone processing
method such as an average density storing method and a
dither matrix method. Further, repeating the T-value
data generation processing according to the image
density information for all pixels can generate binary

10 drive signals that cause individual nozzles to eject
or not eject at each pixel. A noise information
generation means, an estimation means and a correction
information generation means are formed mainly by the
image data processing unit 6 and the CPU 3. Further,

15 it is also possible to perform control by a printer
driver used by a PC.

Denoted 7 is a printing unit which comprises an ink
cartridge 22 and a carriage 20 and ejects ink
according to an ejection pattern generated by the

20 image data processing unit 6 to form a dot image on a
print medium. Designated 8 is a busline in the
printing apparatus for transmitting address signals,
data, control signals and others.

Next, by referring to Fig. 4 to Fig. 11, we will

25 describe a process of generating nozzle information
for print heads, which constitutes one of features of
this embodiment, a process of generating print

information for each nozzle based on the nozzle
information, and an actual printing operation.

In generating print information, it is checked
whether there are any nozzles in print heads whose ink
5 landing positions deviate from a desired print matrix.
If any such nozzles exist, it is necessary to
determine nozzle information, which includes positions
of such nozzles, degrees to which landing positions of
ink droplets ejected from these nozzles deviate from
10 the print matrix and, depending on circumstances,
sizes of landing ink droplets and shapes of ink dots
formed.

For this purpose, a test pattern (step pattern)
such as shown in Fig. 4 is printed using an apparatus
15 of Fig. 1. The step pattern consists of short printed
line segments, eight segments from eight nozzles in
each row, formed by causing each nozzle to eject color
dots continuously or non-continuously over a short
distance. This test pattern printing is performed for
20 a required number of nozzles. This step pattern
indicates by how much distance the ink dots formed
deviate in a vertical direction in the figure from the
ideal print matrix MT. More specifically, the printed
test pattern (or step chart) is scanned by a sensor
25 not shown to measure by how many micrometers the line
segments deviate from their ideal landing positions.
The measured deviations are used as nozzle profile

information. Rather than using the sensor, it is also
possible to visually determine deviated positions and
amounts of deviation to generate nozzle profile
information and input this information into the
5   printing apparatus. This nozzle information is
prepared for each print head.

Dot position deviations can be determined as
follows. An ideal step chart as a reference is
generated in advance using a general printing method
10   or a silver salt picture. Then, a step chart is test-
printed on the reference step chart to measure
deviations from the ideal print matrix. Alternatively,
the printed step chart may be read by a scanner not
shown and checked against the ideal print matrix by
15   considering the nozzle positions to calculate
deviations.

As a further nozzle profile information generation
method, it is also possible to print a dot chart, as
shown in Fig. 5, consisting of independent ink dots
20   from individual nozzles formed on a print medium and
to read, by the method described above, deviations
from the ideal print matrix in X and Y directions and
diameters and shapes of ink dots.

An image print signal can be generated by a method
25   commonly used in ordinary ink jet printing apparatus.
In this embodiment, an input image is color-separated
into images of three primary colors, such as C, M and

Y, that match the ink colors of print heads. Then, the color-separated images are binarized by an error spreading method.

Next, we will explain about a method of generating
5   head correction (HC) data based on a nozzle profile and a method of generating print data to control ejection/non-ejection operations of nozzles in print heads by performing conversion processing on an image to be printed.

10   Fig. 7 shows a basic concept of this embodiment. That is, Fig. 7 illustrates an ideal print matrix MT and a state of ink dots that have landed ideally on the ideal print matrix MT. The ideal print matrix MT refers to a virtual matrix set on a print medium. When
15   a solid image is formed by arranging ink dots of a certain shape in matrix on a print medium, minimum unit print areas that match individual dots in one-to-one correspondence are unit matrices MT1. The unit matrices are also referred to as pixels. For the sake
20   of simplification, the ideal print matrix MT of this embodiment comprises square unit matrices MT1 arranged in the main scan direction (in the figure, horizontal direction) and in the subscan direction (in the figure, vertical direction), as shown in Fig. 7. Depending on
25   a resolution of an image and a print density, the arrangement of the unit matrices MT1 may be other than that shown in Fig. 7. The unit matrices MT1 may have

other shapes than square. For example, rectangular
unit matrices may be arranged in the main scan
direction at two times the pitch of the subscan
direction.

5   When ink is landed on the ideal print matrix MT,
ink droplets land on a print medium normally as almost
circular dots. It is therefore assumed that ink dots
that have landed ideally have a shape of perfect
circle, and a diameter of perfect circle is set equal
10 to a diagonal length of a unit matrix MT1.

        A state of ideally landed ink dots is shown in Fig.
7A. The dots shown here schematically represent a
state of a solid image that was printed by ejecting
ink droplets from all of eight nozzles arrayed in a
15 vertical direction in a print head not shown while
moving the print head in the main scan direction X.
Fig. 7A illustrates a state of ink dots formed by ink
droplets landing ideally on a print medium, and Fig.
7B illustrates a state of ink dots formed by ink
20 droplets failing to land ideally on the print medium.

        In the state of Fig. 7A, ink droplets ejected from
the nozzles of the print head have landed correctly on
the individual unit matrices MT1 in the ideal print
matrix MT without a deviation. Therefore, an
25 arrangement of dots in the vertical direction (Y)
coincides with a vertical arrangement of nozzles in
the print head. For example, third dots d3 from the

top in the figure are dots ejected from a third nozzle from the top of the nozzle group of the print head; and fourth dots d4 from the top are dots ejected from a fourth nozzle from the top of the nozzle group.

5   In contrast to the above, an example state of ink dots formed when ink droplets from the print head fail to land on a print medium ideally is shown in Fig. 7B.

     In the figure, dots d2 formed by ink droplets ejected from a second nozzle are shifted from their

10   ideal positions in X1 and Y2 directions (toward upper right). Dots d3 formed by ink droplets ejected from a third nozzle are shifted in a Y1 direction and land almost on unit matrices where ink droplets ejected from the fourth nozzle should have landed.

15   Further, dots d4 formed by ink droplets ejected from a fourth nozzle are shifted in a Y2 direction and land on unit matrices where ink droplets ejected from the third nozzle should have landed.

     Dots d6 formed on a print medium by a sixth nozzle

20   have a larger diameter because their ink volumes are larger than those from other nozzles.

     Further, dots d7 formed by ink droplets ejected from a seventh nozzle have a smaller diameter because their ink volumes are smaller than those from other

25   nozzles or because ejected ink droplets are split.

     Although the ink dots are shown as true circles in Fig. 7, they may not be formed into perfect circles

depending on a kind of print medium and a status
change of ink that occurs from ejection to landing. As
shown in Fig. 6, ink dots may take a variety of shapes
on a print medium other than perfect circles. For
5   example, variations in ink ejection volume among
nozzles will result in variations in dot size, and as
ink droplets that have landed on a print medium are
absorbed and fixed in paper surface, ink penetrates
into fibers of paper, forming complex shapes of dots
10   as shown. Further, when ink droplets fail to land
vertically on a print medium or are applied a moment
as by wind, the dots may form into an oval shape or
may be broken into fragments.

To describe in more detail, in a process ranging
15   from an ink ejection from print head nozzles to a dot
landing on a print medium, ink droplets landing
position sometimes deviate from an ideal landing
position. The ejected ink droplets may not fly in an
intended direction or receive resistances as they fly.
20   Even after landing on a print medium, ink droplets are
affected by an uneven surface of the print medium and
their abilities to soak and fix in the print medium.
Because of these uncontrollable factors, forming dots
of a perfectly uniform shape at appropriate positions
25   is difficult to achieve. That is, it is extremely
difficult to form ideal dots such as shown in Fig. 7A.

To deal with this difficulty, it is conventional

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practice to perform correction processing such as head
shading. An idea behind the conventional head shading
is as follows. Since positions on a print medium
printed by a nozzle with a large ink ejection volume

5   have a high density and positions printed by a nozzle
with a small ink ejection volume have a low density, a
chart of a predetermined density is printed on a print
medium and actual densities of the printed chart are
measured and matched against the corresponding nozzle

10   positions. Then corrections are made to lower the
density at portions where the measured image density
is higher than normal and to increase the density at
portions where the measured image density is lower
than normal. This density adjustment to improve an

15   image quality is achieved by modifying a drive control
for each nozzle, i.e. by shortening a drive pulse for
nozzles whose ejection volumes are large and raising a
drive voltage for nozzles whose ejection volumes are
small.

20   With this head shading correction, however, there
are cases where correction cannot be made and desired
effect not obtained. For example, when ink droplets
ejected from the third nozzle and the ink droplets
ejected from the fourth nozzle cross each other and

25   land as shown in Fig. 7B, a desired effect from the
correction may not be produced. That is, when the
density of the third unit matrices is high, this

problem is traced to an improper ejection volume of the fourth nozzle. In this case, if the head shading processing is performed by matching read image densities against nozzle positions and reducing the

5　ejection volume of the third nozzle, as described above, it is understood that the correction of the ejection volume does not work well for the correction of image density variations because the ink dots d3 ejected from the third nozzle land on fourth unit

10　matrices.

In another example, when dot landing positions deviate from an ideal print matrix in X and Y directions, the deviated dots increase the density of an adjoining matrix line and decrease the density of

15　an intended matrix line. In this case, performing the conventional head shading results in a correction that increases the density of the adjoining matrix line associated with the deviated nozzle because the head shading does not take the landing position deviations

20　into account. As a result, the density of the adjoining matrix line is further increased, rendering an accurate correction impossible.

The present invention is intended to eliminate problems that could not be solved by the conventional

25　method and to enable more precise corrections. With this invention, there is a situation in which a correction opposite to that of the conventional method

is performed. For example, if a nozzle assigned to an
N-th raster printing is given correction data that is
suited when the ejection volume of this nozzle is
small, this invention may perform a correction on an
5   image input signal to make it still smaller based on
estimation-calculated correction data. This is
explained as follows. When nozzles adjoining the N-th
raster nozzle have deviations in the ink ejection
direction and dots formed by these adjoining nozzles
10   overrun their own print areas into the print area of
the N-th raster, the N-th raster image density may
increase, affected by the overrunning portions of the
adjoining raster dots. In this case, if the nozzle
that prints on the N-th raster has a small ejection
15   volume, a correction is made in such a manner as will
further reduce the density to minimize visible bands
or density variations in a printed image. That is,
while the conventional correction causes nozzles with
small ejection volumes to perform a higher density
20   printing than an input image signal, the present
invention may perform a correction totally different
from that of the conventional method. With this
characteristic correction this invention minimizes
visible bands or density variations.
25   The problem of visible bands or density variations
have conventionally been dealt with as by averaging
high and low density values of nearby matrix lines or

by reading nearby image areas in addition to reading a
target image area. In the ink jet printing apparatus
currently under pressure to meet an ever-increasing
demand for higher image quality, a more precise
5   correction technique is being called for.

    To meet this requirement, the first embodiment of
this invention performs processing such as shown in a
flow chart of Fig. 8.

    First, at step S1, step charts such as shown in Fig.
10 4 are printed so that the state of ink droplets from
individual nozzles that have landed on a print medium
can be observed. Next, the printed charts are read by
an optical sensor not shown (step S2) and, based on
the data thus read, deviations of the landing
15 positions from an ideal print matrix are measured.
This measurement may be made visually. After the dot
chart of Fig. 5 is printed, the size and shape of dots
that have landed on a print medium may be measured
using an optical sensor not shown to determine the
20 ejection volume of each ink droplet.

    If this measurement finds that some dots are not on
the ideal print matrix, that some dots have diameters
different from an ideal dot diameter, or that some
dots have shapes different from an ideal dot shape,
25 the nozzles that formed these dots are determined as
faulty nozzles. Alternatively, without making a check
for faulty nozzles, it is possible to execute a step

for automatically generating nozzle profile
information for all nozzles.

If no faulty nozzles are detected, the processing
moves to step S6 where a desired image is printed
5   without performing correction processing.

If at step S2 a faulty nozzle is found, nozzle
profile information described later is generated for
each of the nozzles making up a print head. In this
embodiment a Y deviation value is used as an important
10   parameter of the nozzle profile information. Let a
direction of column of nozzles making up the print
head (subscan direction) be a Y direction and a main
scan direction in which the print head is moved
relative to a print medium be an X direction. Then,
15   the Y deviation value means an amount of deviation in
the Y direction between a landing position of an ink
droplet ejected from a nozzle (center position of a
dot) and a center position of the corresponding unit
matrix (ideal lattice point) of the ideal print matrix
20   MT. Thus, suppose that, in performing a one-scan (1-
pass) printing, a nozzle pitch is set equal to the
size of unit matrices of ideal landing matrix or to
1,200 dpi (about 20 μm). If the landing position of an
ink droplet ejected from an m-th nozzle is deviated by
25   about half a pixel toward (m-1)st or (m+1)st nozzle,
then the Y deviation value will be +10 μm or -10 μm
and this value is stored as the nozzle profile

information. At the same time, whether or not a diameter of this ink dot (which is determined, for example, by the ejection volume) is larger than an ideal ink dot diameter is also managed as the nozzle
5   profile information.

Returning to Fig. 8, the operation that follows step S2 will be explained. As described above, the Y deviation value of faulty nozzles are measured at step 3 and, based on the measured values, nozzle profile
10 information is generated (step S3). Next, by referring to the nozzle profile information, HS data is generated (step S4). Based on the HS data, HC data (Head Correction Table) that corresponds to the size of input image print data is generated (step S5). Then,
15 using the generated HC data, the print data of input image is transformed and a printing operation is executed according to the transformed print data (step S6).

Now, a generation of a variety of information,
20 performed in and after step S4, will be explained in detail by referring to Fig. 9 to Fig. 11.

Fig. 9A schematically illustrates, from let to right, a print head 21, an ideal print matrix MT, a state of ink dots that landed ideally on the ideal
25 print matrix MT, and a state of ink dots that failed to land ideally on the ideal print matrix MT. For simplicity of explanation, the print head 21 is shown

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to have only five nozzles. Fig. 9B is an enlarged view
showing details of central three ink dot rows in the
dot group of Fig. 9A.

     Data generation is performed by identifying those
5   nozzles which ejected ink dots covering at least a
part of a particular matrix line of the ideal print
matrix MT as determinant nozzles that affect a density
of that matrix line and by determining a percentage of
that portion of each ink dot from the determinant
10 nozzles which affects the density of that particular
matrix line.

     For example, let us consider a case in which ink
droplets ejected from (m-1)st, m-th and (m+1)st
nozzles form dots d(m-1), d(m), d(m+1), as shown in
15 Fig. 9B. How these dots affect the density of an m-th
matrix line is determined, as follows. A portion of
the ink dot d(m-1) formed by the (m-1)st nozzle that
overlies the m-th matrix line and affects the density
of that line (a hatched portion in a left nozzle
20 column in Fig. 9B) is 10% of an ideal dot. A portion
of the ink dot d(m) ejected from the m-th nozzle which
affects the m-th matrix line (in Fig. 9B, a hatched
portion in a center nozzle column) is 80% of an ideal
dot. A portion of the ink dot d(m+1) ejected from the
25 (m+1)st nozzle which affects the m-th matrix line (in
Fig. 9B, a hatched portion in a right nozzle column)
is 5% of an ideal dot. This dot landing state is equal

in printed density to 95% of an ideal dot landing
state.

While we have focused our attention on a particular
line on the print matrix in this case, it is possible
5   to determine a percentage of an affecting portion of
each adjoining dot for each target unit matrix MT1, as
shown in Fig. 10.

The percentage of dot portions affecting the
density of a particular matrix line (degree of
10 influence) can be determined as follows by referring
to nozzle profile information, particularly Y
deviation values in the information.

Suppose, for example, that a nozzle pitch
(equivalent to the unit print matrix size) is 20 μm
15 (equivalent to 1,200 dpi) and that every nozzle forms
an ink dot 30 μm in diameter on a print medium. It is
also assumed that a direction from (m-1)st line to
(m)th line is taken as a positive direction and that a
Y deviation value of a dot from the (m-1)th nozzle is
20 +5 μm, a Y deviation value of a dot from the (m)th
nozzle is +10 μm, and a Y deviation value of a dot
from the (m+1)th nozzle is -5 μm. As shown in Fig. 11A,
the density of the m-th matrix line is determined from
the following formulas based on the dots from (m-1)st
25 nozzle, (m)th nozzle and (m+1)st nozzle.

As shown in Fig. 11B, let a dot radius be R, a dot
area be S, a Y deviation value be Y and a width of a

print matrix line be P. Then, a percentage (degree of influence) of that portion of dot d(m-1) affecting the density of the m-th matrix line, $Z_{m-1}(L)$ (L is a number representing a matrix line position), is determined by

5      $Z_{m-1}(L) = R^2 \times \cos\theta^{-1}((P/2 - Y_{n-1})/R) - (P/2 - Y_{n-1}) \times$
       $\sqrt{(R^2 + (P/2 - Y_{n-1})^2)}$

A degree of influence of that portion of dot d(m+1) affecting the m-th matrix line, $Z_{m+1}(L)$, can also be determined in the similar manner.

10   The center angle θ is an angle formed by two line segments (radii) connecting a dot center and two intersecting points between the dot and the m-th matrix line.

Further, a degree of influence of that portion of

15   dot d(m) affecting the m-th matrix line, $Z_m(L)$, can be obtained from the following equation.

       $Z_m(L) = 100 - Z_m(L-1) - Z_m(L+1)$ (%)

If different nozzles have different dot radii, the degree of influence can be calculated by substituting

20   individual radius values.

Further, if the dot shape is not a true circle, the degree of influence can also be determined in the similar manner though the calculation becomes complicated. In that case, a complex shape may be

25   approximated to a predetermined simple shape that allows for simpler calculation.

By analyzing a printed state of a particular matrix

line (L), particularly nozzles that affect a density
of that matrix line, the density of the matrix line
can be estimated.

That is, if D_i stands for a density produced by an
5   ideal printed dot and D_L for an estimated density of
line L, the estimated density D_L is expressed by the
following equation, which sums up degrees of influence
Z(L) of (m-a)th to (m+b)th nozzles (a and b are
positive integers).

10       $D_L = k_{den}(Z_{m-a}(L) ... Z_{m-1}(L) + Z_m(L) + Z_{m+1}(L) ... Z_{m+b}(L))$

k_{den} is a coefficient used to determine an actual
density from a dot area and can be calculated by
measuring a density of a printed image.

A coefficient H_{conf} for head correction is given by
15       $H_{conf}(L) = k_{head} \times D_L/D_i$
This gives a measure of how the printed matrix
contributes to an actual density on a print medium.

k_{head} is a coefficient to finely adjust a
coefficient K, and varies depending on a print medium
20   used and a printing environment and can be determined
experimentally.

The H_{conf} is used to correct an image to be printed
and to control a drive signal for the ejection
operation of each nozzle to change an ejection volume
25   during the head shading processing.

As described above, in a printing process, if ink
dots intended for other matrix lines land overlapping

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a matrix line of interest, the above embodiment
considers an effect the dots of other lines have on a
density of the matrix line of interest in making
printing operation corrections. Hence, even with a
5 print head having nozzles that eject ink droplets with
deviations in the Y direction, a satisfactory
correction effect can be produced, thereby forming
high quality images.

Although in the above embodiment a nozzle
10 correction coefficient is calculated for each matrix
line L, it is possible to use degrees of influence on
a particular matrix line L from adjoining matrix lines,
$Z_{m-1}(L)$, $Z_m(L)$, $Z_{m+1}(L)$, in calculating a correction
coefficient for an (m-1)st nozzle that prints on a
15 matrix line L-1 adjacent to the matrix line L. More
specifically, a coefficient H_{nozz} for head correction is
calculated as follows. In the processing for a matrix
line L, a head correction is performed also on the (m-
1)st nozzle that is intended to print on the matrix
20 line L-1. That is, corrections are performed on the
nozzles that affect the density of the matrix line L
and/or on an image printed by these nozzles.

If a matrix line L printed by a nozzle m is
affected by ink dots formed by nozzles that print on
25 matrix lines L-1, L, L+1, the coefficient H_{nozz} for head
correction is given by

$H_{nozz}(L) = Z_m(L-1) \times H_{conf}(L-1) + Z_m(L) \times H_{conf}(L) +$

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$$Z_m(L+1) \times H_{conf}(L+1))$$

Though not shown in the above equation, any desired coefficient may be applied to each term as needed. The above equation means that the correction coefficient

5　for the nozzle m that prints on the matrix line L also takes into account an estimated print density correction for the matrix lines (in the above equation, L-1 and L+1) which are affected by ink dots formed by the nozzle m.

10　In other words, based on the degrees to which ink dots ejected from the nozzle m affect the matrix lines L-1 and L+1, i.e., the states of these matrix lines L-1, L, L+1, the head correction data is calculated.

With the method described above, even if ink dots

15　are greatly deviated from an intended matrix line toward an adjoining matrix line, a matrix line correction can be realized by correcting image data for the nozzles that affect the matrix line of interest and/or by correcting ejection volumes of

20　these nozzles. In this way an excellent correction function can be obtained.

[Second, Third and Fourth Embodiment]

In the first embodiment, a Y deviation value of each ink dot is used as an important parameter in

25　setting nozzle profile information. The present invention can also use other values in addition to the Y deviation value as the parameter.

For example, in a second embodiment of this
invention shown in Fig. 12, a dot diameter in addition
to the Y deviation value of a faulty nozzle is used as
the parameter, as shown at step S13. Further, in a
5   third embodiment of the present invention shown in Fig.
13, an X deviation value in addition to the Y
deviation value and dot diameter is used as the
parameter, as shown at step S23. Further, in a fourth
embodiment of the present invention shown in Fig. 14,
10   a dot shape in addition to the Y deviation value, dot
diameter and X deviation value is used as the
parameter, as shown at step S33.

   Setting as many parameters as possible, as
described in the second to fourth embodiments, can
15   produce more precise nozzle profile information, which
in turn provides an image with an excellent tonality
and an improved immunity from banding, compared with
the first embodiment. In Fig. 12 to Fig. 14, steps
other than the above-mentioned steps S13, S23, S33 are
20   almost similar to the steps S1, S2 and S4-S6 that have
been described in the first embodiment.

   Further, this invention can also be applied without
a problem to ink jet printing apparatus that use a
plurality of dark and light inks and large and small
25   dots for each ink color. In that case, a highly
enhanced image quality can be reproduced on a print
medium.

[Example 1]

Next, some examples of printing performed by using the ink jet printing apparatus and the printing method according to the first embodiment of the invention
5 will be explained.

A print head used has a resolution of 1,200 dpi and an array of 4,096 nozzles, with an ink ejection volume (volume of each ink droplet) set to 4.5±0.5 pl.

Inks containing colorants have the following
10 compositions.

(Prescription: Y ink)

- Glycerine	5.0 parts by weight
- Thiodiglycol	5.0 parts by weight
- Urea	5.0 parts by weight
- Isopropyl alcohol	4.0 parts by weight
- Dystuff, C.I. Direct Yellow 142	2.0 parts by weight
- Water	79.0 parts by weight

(Prescription: M ink)

- Glycerine	5.0 parts by weight
- Thiodiglycol	5.0 parts by weight
- Urea	5.0 parts by weight
- Isopropyl alcohol	4.0 parts by weight
- Dystuff, C.I. Acid Red 289	2.5 parts by weight
- Water	78.5 parts by weight

(Prescription: C ink)

- Glycerine	5.0 parts by weight
- Thiodiglycol	5.0 parts by weight

- Urea	5.0 parts by weight
- Isopropyl alcohol	4.0 parts by weight
- Dystuff, C.I. Direct Blue 199	2.5 parts by weight
- Water	78.5 parts by weight

5 (Prescription: K ink)

- Glycerine	5.0 parts by weight
- Thiodiglycol	5.0 parts by weight
- Urea	5.0 parts by weight
- Isopropyl alcohol	4.0 parts by weight
10 - Dystuff, Food Black 2	3.0 parts by weight
- Water	78.0 parts by weight

As a print medium, PB·PAPER (Canon make) for
electrophotographic picture and ink jet printing was
used. Printing operations were performed using these
15 color inks and print medium.

A printing operation was controlled according to a
control sequence shown in the flow chart of Fig. 8.
First, a step chart of Fig. 4 was output and then read
at a resolution of 4,800 dpi by an optical sensor
20 (scanner) not shown. At this time, the chart may be
marked to match individual nozzles to their associated
printed line segments in their positional relationship.
Then, each of the printed line segments was subjected
to line-thinning processing to determine a gravity
25 center of an ink dot and measure a Y deviation value
of the ink dot from its ideal landing position. This
process was done for all nozzles to generate nozzle

profiles.

Ink dots ejected from nozzles had a landing precision of 6 μm in σ value and a maximum deviation of +25 μm. Using this nozzle profile, a printed density was estimated for each matrix line from the formulas described earlier and head correction data (HC data) was generated. Then, a density grayscale value in print data of an image to be printed was corrected for each line assigned to the associated nozzle. A plurality of kinds of ink described above were used for printing. As a result, a high-quality image with fewer banding phenomena and no white stripes was obtained.

In contrast to the above, the printing was done by omitting the head correction processing while keeping other conditions similar to those of the above example. This produced a poor-quality image with visible white stripes or bands.

Performing the conventional head shading processing in the printing resulted in an image with reduced density variations but with persisting visible bands. An image quality degradation is obvious when compared with an image produced by the above example method.

Next, a fifth embodiment of the present invention will be explained. In this embodiment, too, the construction shown in Fig. 1 to Fig. 3 is used as in the preceding embodiment.

A generation of print head nozzle information, one
of features of this embodiment, a generation of print
information for each nozzle based on the nozzle
information, and an actual printing operation will be
5   explained by referring mainly to Fig. 15 and Fig. 16.

To generate the print information the following
process needs to be taken. First, a check is made to
see if there is any among the print head nozzles that
projects ink droplets with deviations from an ideal
10 print matrix. If there is such a nozzle, nozzle
information needs to be determined which includes an
amount of deviation of an ink droplet ejected from
that nozzle with respect to the print matrix and, if
necessary, a size and shape of an ink dot formed by
15 the nozzle.

To obtain the nozzle information, a first step to
be taken is to print a step pattern PT1, such as shown
in Fig. 4, by using a printing apparatus of Fig. 1.
The step pattern PT1 consists of short printed line
20 segments, eight segments from eight nozzles in each
row, formed by causing each nozzle to eject color dots
continuously or non-continuously over a short distance.
This pattern printing is performed for a required
number of nozzles. This step pattern PT1 indicates by
25 how much distance the ink dots formed deviate in a
vertical direction in the figure from the ideal print
matrix MT. More specifically, the printed step pattern

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(or step chart) PT1 is scanned by a sensor not shown
to measure by how many micrometers the line segments
deviate from their ideal landing positions. The
measured deviations are used as nozzle profile
5   information. Rather than using the sensor, it is also
possible to visually determine deviated positions and
amounts of deviation to generate nozzle profile
information and input this information into the
printing apparatus. This nozzle information is
10   prepared for each print head.

Dot position deviations can be determined as
follows. An ideal step chart as a reference is
generated in advance using a general printing method
or a silver salt picture. Then, a step chart is test-
15   printed on the reference step chart to measure
deviations from the ideal print matrix. Alternatively,
the printed step chart may be read by a scanner not
shown and checked against the ideal print matrix by
considering the nozzle positions to calculate
20   deviations.

The test pattern may be printed as a solid pattern
formed of solid images. This solid pattern need only
have a uniform print density in a predetermined area.
The solid pattern may, for example, be a check pattern
25   PT2 as shown in Fig. 15. If the solid pattern PT2 is
completed by one printing scan (1-pass printing) using
a print head containing faulty nozzles, stripes or

bands are formed or density variations become visible, as shown in Fig. 15B. These variations are read by sensor or by sight to generate the nozzle profile information.

5   Further, a dot chart may be formed by causing all the nozzles to eject ink to form independent ink dots on a print medium, as shown in Fig. 5. Using the method described above, deviations of these ink dots from the ideal print matrix in X and Y directions and

10   diameters and shapes of the dots are read to generate the nozzle profile information.

Image print signals can be generated by a method commonly employed by ordinary ink jet printing apparatus. In this embodiment, an input image is

15   color-separated into three CMY primary colors for print heads of the corresponding colors and then the color-separated images are binarized by an error spreading method.

Next, we will describe a method of generating head

20   correction (HC) data based on the nozzle profile and a method of performing, based on the HC data, conversion processing on an image to be printed and generating print data that controls an ejection/non-ejection operation of each of print head nozzles.

25   First, a grayscale correction control will be explained.

A position on a print medium that is printed by a

nozzle with a large ink ejection volume (volume of ink droplet) in one ejection operation has a high density, while a position printed by a nozzle with a small ink ejection volume has a low density. A chart (solid

5   chart PT2 of Fig. 15) of a pattern with a uniform density is printed on a print medium. Then actual densities of printed positions are measured and matched against the nozzle positions. Corrections are made to lower the density at portions of the printed

10   image where the measured density is higher than normal and to increase the density at portions where the measured density is lower than normal. This density adjustment to improve an image quality is achieved by a so-called head shading, which modifies a drive

15   control for each nozzle to control the ink ejection volume, as by shortening a drive pulse for nozzles whose ejection volumes are large and raising a drive voltage for nozzles whose ejection volumes are small, and which increases or decreases print data at

20   corresponding positions on an image to be printed. At the same time that the head shading is performed, the ink droplet deviation correction such as described in the preceding embodiment is also performed to enhance an image quality.

25   In the fifth embodiment of this invention, the control is performed, for example, according to a control sequence of Fig. 16.

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First, at step S1, a step chart of a step pattern PT1 and a solid chart of a solid pattern PT2 are printed, as shown in Fig. 15. Next, a printed density of the solid chart is measured by an optical sensor

5   not shown and, based on measured density variations in the solid chart PT2, variations in ink ejection volume among nozzles are determined and stored as head shading data (HC data) (step S2).

At step S2, the printed step chart is read by an

10   optical sensor not shown and, based on the data thus read, deviations between dot landing positions and an ideal print matrix are measured. This measurement may be done visually. Further, the volumes of ink droplets ejected are measured by printing a dot chart of Fig. 5

15   and measuring the sizes and shapes of dots that have landed on a print medium with an optical sensor not shown.

If the result of the measurement finds that some ink dots are not positioned on the ideal print matrix,

20   that their diameters differ from an ideal diameter or that their shapes differ from an ideal shape, then those nozzles that have ejected ink droplets to form these dots are determined as faulty nozzles. Alternatively, without performing the faulty nozzle

25   check step, the processing may proceed to a step of automatically generating nozzle profiles for nearly all nozzles. Other nozzles that are determined to be

not faulty do not undergo the correction processing
and are allowed to perform a printing operation
according to image data.

When there are faulty nozzles, nozzle profile
5   information described later is generated for each of
the nozzles making up the print head. That is, in this
embodiment, the head shading information (HS) obtained
from the solid chart and the nozzle profile
information obtained from the step chart are generated.
10   At step S3, as in the preceding embodiments, a
measurement is made of a Y deviation value, which
constitutes an important parameter in generating the
nozzle profile information.

Following the generation of the nozzle profile
15   information through the measurement of the Y deviation
values of the faulty nozzles, step S4 checks the HS
data and the nozzle profile data (NP data) for faulty
nozzles.

That is, the NP data is checked to see if there is
20   any nozzle that causes so large a dot landing position
error with respect to the ideal print matrix as will
exceed a predetermined value (in this case, 1/2
resolution). Such a nozzle is determined as a "large-
deviation failed nozzle".
25   There is also a case where, although the dot
landing deviation is small, the ejection volume
variation may be large enough to cause a density

variation such that a density of an image formed by ejected ink droplets deviates from an appropriate density by an amount in excess of a predetermined allowable range. For example, if a density variation

5 is produced by a certain nozzle during a 1-pass printing of a solid pattern, that nozzle is determined simply as a "faulty nozzle". In real print heads, particularly those with an elongate array of nozzles, large-deviation failed nozzles may concentrate in one

10 area and nozzles with large ejection volume variations in another area. Though in rare cases, the print head may have non-uniform nozzle diameters and shapes and nozzles may even be deformed by stresses. In a conventional practice, a print head containing such

15 nozzles is identified as faulty and entirely disposed of. With this embodiment, however, those print heads that have so far been treated as faulty products can be restored for use depending on how bad the print heads are. Also in the event of worn nozzles caused by

20 a long period of use or ejection-failed nozzles due to ingress of dust or large-deviation failed nozzles, this embodiment can make up for them.

When a large-deviation failed nozzle should occur, HC data (head correction table data) is generated for

25 those nozzles in the vicinity of that failed nozzle by a deviation correction control method described below (step S5). The HC data is integrated with the HS data

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to generate HS data for the entire print head. Using the generated HS data, a grayscale correction is performed on an output image signal to generate corrected print data (step S6). A printing operation

5   is now executed according to the corrected print data (step S7).

At step S4 above, if no large-deviation failed nozzle is found, the HC data generation at step S5 is omitted and a grayscale correction is performed on

10 image print data by using the HS data which was determined at step S2, i.e., the original HS data not considering the HC data.

In this embodiment, as described above, the HC data generation is not performed for all the nozzles but

15 for only those faulty nozzles that cause large dot position deviations. This embodiment therefore improves the data processing speed substantially when compared with the configuration that generates the HC data for all nozzles. That is, since the large-

20 deviation failed nozzles are very few in comparison with the total number of nozzles of a print head and since this embodiment executes calculation operations for only the very few nozzles, the time it takes to generate the HC data is minimal and has almost no

25 adverse effects on the printing operation as a whole, assuring an efficient printing of an image with a good quality.

While the present invention is particularly effective in a 1-pass printing system, it is also effectively applicable to a so-called multipass printing system in which one and the same print area

5   is scanned multiple times by different groups of print head nozzles to complete an image on that area. In general multipass printing system, after a faulty nozzle is detected, the area printed by that faulty nozzle is printed by other nozzle groups during

10 different scans to alleviate an image quality degradation caused by the faulty nozzle. With this invention, however, the image quality degradation by a faulty nozzle can be prevented by a simple processing method in virtually the same scan. Combined with the

15 advantage of the multipass printing system, the present invention therefore can form images of even higher quality.

Further, this invention is particularly effective in an ink jet printing apparatus in which a plurality

20 of nozzles are arrayed in a direction almost perpendicular to the printing scan direction in such a way that an interval between adjoining nozzles that can print simultaneously in the same scan is set almost equal to an interval of pixels of an image to

25 be printed, as shown in Fig. 2, i.e., in a full-line type ink jet printing apparatus that completes an image printing in a single scan. The full-line type

ink jet printing apparatus basically has advantages over the multipass printing system in that it has a simpler construction and that it has a much faster printing speed. Applying the present invention to the

5 full-line type system can improve an image quality and thus realizes an ink jet printing apparatus with excellent performances in terms of cost, printing speed and image quality.

Where the interval between adjoining nozzles is

10 wider than the interval between adjoining print matrix lines, i.e., the resolution of the print head is lower than that of the print matrix, an interlace system may be employed in which the printing position of the print head is shifted by a distance smaller than the

15 nozzle interval to print dots between the already printed matrix lines of dots, or another print head with a higher resolution may be used which ejects ink droplets of the same color. In that case, even if another print head with a different resolution is used,

20 the printing can be done in virtually the same way with respect to the print matrix as when these print heads perform printing in the same scan. Therefore, this invention can also be applied suitably to the interlace printing system.

25 However, if those nozzles that print on adjoining matrix lines are actually put close together, the ink jet printer can be constructed in a simpler

configuration and print at faster speed, as described above. Therefore, this invention is particularly suited for full-multiple type printers.

Adjoining nozzles are preferably set to the
5 following resolution, depending on a purpose of image printing. For example, when a small-size image, like a so-called pocket picture, is to be ink-jet printed at high quality, adjoining nozzles are preferably set to an interval of about 300 dpi (100 μm) if their ink
10 ejection volume is around 40±10 pl. If the nozzles have an ink ejection volume of about 10±5 pl, they are preferably set closer together at around 600 dpi (40 μm). Further, it is desired that the interval be set to 1,200 dpi (20 μm) for the ink ejection volume of
15 about 5±2 pl and to 2,400 dpi (10 μm) for the ink ejection volume of about 2±1 pl.

Unlike the small-size picture, which is to be viewed close-up, a large-size image that is viewed at some distance is printed with nozzles having a larger
20 ink ejection volume and spaced at relatively wider intervals. In this case, too, this invention is suitably applied.

In addition to the printing apparatus using a print head that ejects ink by a thermal energy generated
25 from electrothermal transducers, this invention is also applicable to printing apparatus with a print head that ejects ink by piezoelectric elements. In

other words, the present invention can be applied to any kind of ink jet printing apparatus that ejects ink from nozzles.

[Example 2]

5   Next, Example 2 of a printing operation performed by the ink jet printing apparatus and the printing method of the fifth embodiment of this invention will be described in the following.

A print head, as in the previous Example 1, has
10   4,096 nozzles arranged at a resolution of 1,200 dpi, with a single ink ejection volume (volume of an ink droplet) set to 4.5±0.5 pl. Compositions of inks containing colorants are the same as those in Example 1.

15   A printing operation control was performed according to a sequence shown in the flow chart of Fig. 16.

First, a step chart of Fig. 4 was output and the printed step chart was measured by an optical sensor
20   (scanner) not shown at a resolution of 4,800 dpi. Individual line segments of the step chart were subjected to line-thinning processing to determine gravity centers of ink dots and thereby measure Y deviation values of ink dots from ideal dot landing
25   positions. At the same time, a solid printed chart was also read to determine printed density variations and, according to the previously explained method, generate

HS data (density variation correction data). Based on the Y deviation values, NP data (nozzle profile data) were generated for all nozzles.

Ink dots ejected from nozzles had a landing

5   precision of 6 μm in σ value and a maximum deviation of +25 μm. A nozzle that forms an ink dot whose Y deviation value exceeds one-half the nozzle pitch of 1,200 dpi (21.7 μm), i.e., 10.8 μm, is treated as a large-deviation failed nozzle. For nozzles in the

10   vicinity of that large-deviation failed nozzle (for example, five nozzles before and after the large-deviation failed nozzle), estimated printed densities were calculated using their NP data according to the formulas explained earlier to generate HC (dot

15   position deviation correction data). The HC data (for those nozzles in the vicinity of the failed nozzle having a Y deviation value in excess of one-half the resolution) was substituted for the HS data (density variation correction data) to correct a density

20   grayscale value in the print data of an image to be printed for each of the print matrix lines associated with the respective nozzles. Printing operations were executed using the aforementioned kinds of ink. Printed images obtained had a high quality with

25   reduced visible banding and no white stripes.
     [Example 3]
         In this example, the criterion to determine whether

or not a nozzle in question was a failed nozzle was
set to 25% of the resolution, with other conditions
set equal to those of Example 1. The number of large-
deviation failed nozzles was 50%.

5   In this case, too, a good quality image was
obtained but the data processing time doubled because
of a doubled number of nozzles requiring the dot
deviation correction control.

[Example 4]

10   In this example, the criterion to determine whether
or not a nozzle in question was a failed nozzle was
set to 10% of the resolution, with other conditions
set equal to those of Example 1. The number of large-
deviation failed nozzles was 80%.

15   —In this case, too, a good quality image was
obtained but the data processing time was longer than
the preceding examples because the number of nozzles
requiring the dot deviation correction control
increased.

20 [Example 5]

In this example, the criterion to determine whether
or not a nozzle in question was a failed nozzle was
set to 100% of the resolution, with other conditions
set equal to those of Example 1. The number of large-

25 deviation failed nozzles was 1%.

In this case, an image obtained was of a better
quality than that obtained with the conventional

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method but with not as conspicuous an image quality improvement as in Example 1. However, the data processing time was significantly reduced, when compared with the preceding examples.

5   The present invention achieves distinct effect when applied to a recording head or a recording apparatus which has means for generating thermal energy such as electrothermal transducers or laser light, and which causes changes in ink by the thermal energy so as to

10   eject ink. This is because such a system can achieve a high density and high resolution recording.

A typical structure and operational principle thereof is disclosed in U.S. Patent Nos. 4,723,129 and 4,740,796, and it is preferable to use this basic

15   principle to implement such a system.

The present invention has been described in detail with respect to preferred embodiments, and it will now be apparent from the foregoing to those skilled in the art that changes and modifications may be made without

20   departing from the invention in its broader aspect, and it is the intention, therefore, in the apparent claims to cover all such changes and modifications as fall within the true spirit of the invention.